Brit.J.Sports Med. — Vol. 21, No. 2, June 1987, pp. 9-13

DETERMINANTS OF FIVE KILOMETRE RUNNING PERFORMANCE IN ACTIVE MEN AND WOMEN

R. RAMSBOTTOM, BSc, MPhil, M. G. L. NUTE, BSc and C. WILLIAMS, BSc, MSc, PhD

Department of Physical Education and Sports Science, Loughborough University

ABSTRACT

Previous studies of elite endurance athletes have suggested that success in distance running is attributable to the possession of a high maximal oxygen uptake ($\dot{V}O_2$ max), the utilisation of a large fraction of the $\dot{V}O_2$ max and to running economy. The purpose of the present study was to examine the relationships between these physiological characteristics and running performance in active but not elite men and women. Maximal oxygen uptake values were 57.6 ± 6.2 and 46.6 ± 4.8 $ml.kg.^{-1}min^{-1}$ for the men and women respectively ($p < 0.01$). Running performance was assessed as a 5 km time trial and the men completed this distance in 19.77 ± 2.27 min and the women in 24.44 ± 3.19 min ($p < 0.01$). Maximal oxygen uptake showed strong correlations ($p < 0.01$) with running performance (men, $r = -0.85$; women, $r = -0.80$) but there was only a modest relationship between running economy and performance (men, $r = 0.39$; women, $r = 0.34$). The results of the present study suggest that the faster 5 km performance times recorded by the men were best explained by their higher $\dot{V}O_2$ max values.

Key words: Maximal oxygen uptake, Running economy, Running performance, 5 km run

INTRODUCTION

Many investigations reported in the literature have attempted to identify the physiological attributes associated with distance running success. The possession of a large maximal oxygen uptake ($\dot{V}O_2$ max) has frequently been connected with successful running performance (e.g. Saltin and Åstrand, 1967; Costill et al, 1973). Differences in running economy, which has been defined as the oxygen consumption for a given submaximal treadmill running velocity (Farrell et al, 1979), discriminate between individuals possessing similar $\dot{V}O_2$ max values in terms of performance (Conley and Krahenbuhl, 1980). The ability to utilise a large fraction of the $\dot{V}O_2$ max (Costill et al, 1971), the proportion of slow twitch fibres in the running musculature (Costill et al, 1976), and more recently the rate of accumulation of lactate in the plasma (Farrell et al, 1979) or blood (Sjödin and Jacobs, 1981) have also been recognised as factors which may determine distance running success. The purpose of the present study was to investigate the relationships between $\dot{V}O_2$ max, running economy and running performance in a large group of active men and women, relatively few of whom were trained runners.

METHODS

The subjects recruited for these studies were final year Physical Education students and, in order to obtain a sufficiently large sample of the same population, the investigation was carried out over a four-year period. Measurements were made throughout the study by the same investigators using standard methods and laboratory instrumentation. Laboratory procedures involved the measurement of height and weight and the direct determination of maximal oxygen uptake. This was determined by a continuous incremental grade test (modified after Taylor, Buskirk and Henschel, 1955) on a motor-driven treadmill (Woodway, ELG2). The belt speed was 3.13 $m.s^{-1}$ for both men and women and expired air samples were collected every three minutes until the subjects indicated that they could continue for only one more minute, when a final one minute sample of expired air was taken. A second treadmill test was performed on a separate occasion to determine the oxygen cost of submaximal running. In this sixteen-minute test the subject ran on a level treadmill, the speed of which was increased at the end of each four-minute period. Expired air samples were collected during the final minute of each stage for the determination of oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), and minute ventilation ($\dot{V}E$) (Williams and Nute, 1983). Throughout each test the heart rate of the subject was monitored on an oscilloscope (Rigel) using suitably placed chest electrodes. Both laboratory tests were performed after subject familiarisation with treadmill running.

Running performance was assessed by a 5 km time trial. Of the 124 subjects, 98 (55 men, 43 women) ran on the University athletic track and 26 (14 men, 12 women) ran on a flat, carefully measured 1 km road course while construction work temporarily closed the track. Performance and lap times were recorded using digital stopwatches (Accusplit). Subjects of similar ability ran in groups of not more than six to encourage competition. Because of illness and injury some subjects did not complete all tests ($\dot{V}O_2$ max, $\dot{V}O_2$ submax, 5 km run).

Simple correlation coefficients, linear regressions and t-tests were performed using the Minitab statistical package. Paired observations were used throughout each analysis. A t-test for independent samples was used to test for differences between the means for men and women.

RESULTS

The physiological characteristics of the men and women participating in this study are presented in Table I. The $\dot{V}O_2$ max and $\dot{V}E$ max values of the men were 50.0% and 46.9% greater respectively ($L.min^{-1}$; $p < 0.01$) than those of the women, but there were no significant differences between the maximum heart rate values nor in the oxygen cost of submaximal running at the same velocity (Fig. 1). However, when running velocity was expressed as relative exercise intensity (%$\dot{V}O_2$ max), there was a significant difference between the men and women ($p < 0.01$) (Table II).

When the results for the men and women were combined there was a strong correlation between VO_2 max and running performance ($r = -0.89$) (Fig. 2). Running performance, the estimated oxygen cost and estimated %$\dot{V}O_2$ max utilised during the 5 km run, together with

Address for correspondence:
R. Ramsbottom, BSc, MPhil
Department of Physical Education and Sports Science
University of Technology
LOUGHBOROUGH
Leics. LE11 3TU

TABLE I

Physiological characteristics of the male and female subjects (Mean ± SD)

Subject	Height (cm)	Weight (kg)	$\dot{V}O_2$ max ($L.min^{-1}$)	$\dot{V}O_2$ max ($ml.kg.^{-1}min^{-1}$)	$\dot{V}E$ max ($L.min^{-1}$)	HR max ($b.min^{-1}$)
Males						
n	69	69	69	69	69	64
Mean	178.3	72.7	4.2	57.6	125.9	194
± SD	6.4	9.0	0.6	6.2	14.8	10
Females						
n	55	55	55	55	55	53
Mean	165.6**	59.9**	2.8**	46.6**	85.7**	193
± SD	6.2	7.8	0.4	4.8	10.6	10

** significantly different between males and females $p < 0.01$

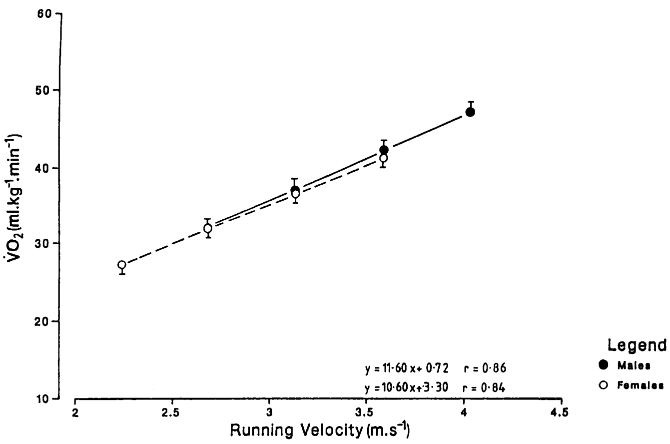

Fig. 1: The relationship between oxygen consumption and submaximal treadmill running velocity for men and women (men n = 58, women n = 44).

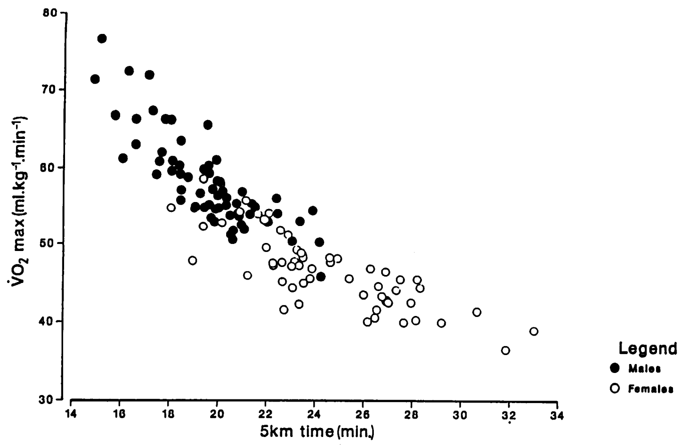

Fig. 2: The relationship between $\dot{V}O_2$ max and 5km running performance for men and women (n = 124).

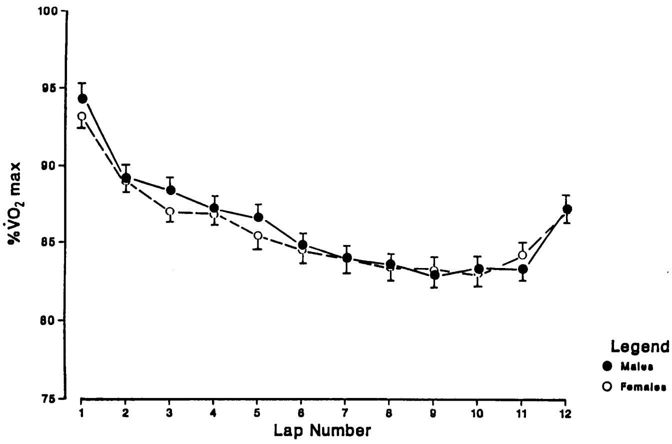

Fig. 3: The estimated %$\dot{V}O_2$ max utilised during a 5km performance test for men and women (men n = 45, women n = 32).

running economy (%$\dot{V}O_2$ at 3.13 $m.s^{-1}$) and relative running economy (%$\dot{V}O_2$ max at 3.13 $m.s^{-1}$) are shown in Table II.

From individual lap times and the relationship between speed and $\dot{V}O_2$ for each individual it was possible to estimate oxygen consumption during the performance run. The men consumed more oxygen than the women in order to sustain their higher running velocity ($p < 0.01$) but there was no significant difference between the %$\dot{V}O_2$ max utilised by men and women during the 5km performance test. Both sexes ran the first and last 400m faster than the intervening laps (Fig. 3).

TABLE II

Running performance, estimated oxygen consumption and estimated %$\dot{V}O_2$ max during a 5km run, together with running economy and relative running economy (at 3.13 $m.s^{-1}$) for the male and female subjects. (Mean ± SD)

Subjects	5km time (min)	$\dot{V}O_2$ max ($ml.kg.^{-1}min^{-1}$)	Performance $\dot{V}O_2$ ($ml.kg.^{-1}min^{-1}$)	Performance %$\dot{V}O_2$ max	Running Economy $\dot{V}O_2$ ($ml.kg.^{-1}min^{-1}$)	Running Economy %$\dot{V}O_2$ max
Males						
n	69	69	59	59	58	58
Mean	19.77	57.6	50.3	87.0	36.9	64.6
± SD	2.27	6.2	5.4	5.8	3.4	10.0
Females						
n	55	55	44	44	44	44
Mean	24.44**	46.6**	41.3**	88.2	36.4	78.4**
± SD	3.19	4.8	4.5	5.1	3.2	10.0

** significant difference between males and females $p < 0.01$

DISCUSSION

Maximal Oxygen Uptake ($\dot{V}O_2$ max)

The $\dot{V}O_2$ max values in the present study (Table I) were similar to those reported by Williams (1981) and Bland (1982) for men and women from a similar active population. The range of $\dot{V}O_2$ max values in the present study was 42.6 to 76.5 $ml.kg.^{-1}min^{-1}$ for the men and 36.4 to 58.6 $ml.kg.^{-1}min^{-1}$ for the women. Maximal oxygen uptake values for elite male endurance athletes have been reported to be in the range 70-80 $ml.kg.^{-1}min^{-1}$ (Costill and Fox, 1969; Pollock, 1977; Davies and Thompson, 1979; Conley and Krahenbuhl, 1980; Sjödin and Schéle, 1982; Colquhoun, 1984). Similarly maximal oxygen uptake values in the order of 60 $ml.kg.^{-1}min^{-1}$ have been reported for elite female runners (Wilmore and Brown, 1974; Davies and Thompson, 1979; Hagan, Strathman, Strathman and Gettman, 1980; Wells, Hecht and Krahenbuhl, 1981).

It is generally accepted that men out-perform women in distance running events, for example Daniels and co-workers (1977) reported that "standards are about 10% slower for women in the 1500- and 3000-meter races and nearly 25% slower over the marathon distance". The present study revealed the female time of 24.44 ± 3.19 min was 24% slower than the time recorded by the male subjects (19.77 ± 2.27 min). The current world records for 5km running show that the time for women (Budd, 14.80 min) is 13.9% slower than that for men (Aouita, 13.00 min).

"Women have approximately the same maximal oxygen uptake per kilogram fat-free body mass as men" (Åstrand and Rodahl, 1977, p. 379). However, male athletes possess a 20-25% higher $\dot{V}O_2$ max than female athletes (Drinkwater, 1973). This 20-30% difference in $\dot{V}O_2$ max ($ml.kg.^{-1}min^{-1}$) "is largely explained by their (female's) higher content of adipose tissue" (Åstrand and Rodahl, 1977, p. 379). Normally active men have been found to possess 13.5 ± 5.8% body fat and normally active women 24.2 ± 6.5% body fat (Durnin and Rahaman, 1967). Male distance runners have been reported to have approximately 7.5% body fat (Costill et al, 1970) and their female counterparts to have 15.2% body fat (Wilmore and Brown, 1974).

Because of their smaller body size a woman's heart is smaller, hence the maximum cardiac output ($\dot{Q}$ max) is limited by her smaller maximum stroke volume compared with a man (Wells, 1985, p. 20). The haemoglobin content of the woman's blood is 10-15% less than that of the man and contains 6% fewer erythrocytes (Åstrand and Rodahl, 1977, p. 134) which results in a lower oxygen carrying capacity of the blood in women. Thus at the same absolute exercise intensity the woman must either deliver more blood to the working muscles or extract more oxygen from the blood supplied to that tissue (Wells, 1985). Expressed another way, the male requires 4.72 L. of blood to transport 1.0 L. of oxygen, whereas the female must pump 5.37 L. of blood to transport the same quantity of oxygen. Thus differences in $\dot{V}O_2$ max, and hence running performance, between men and women are largely explained by differences in maximum cardiac output, the oxygen carrying capacity of the blood and the higher proportion of adipose tissue in the female.

A strong correlation was found between $\dot{V}O_2$ max and 5km time for both the men ($r = -0.85$; $p < 0.01$) and women ($r = -0.80$; $p < 0.01$). Similarly strong correlations have been reported by other investigators over different performance distances when athletes with a range of $\dot{V}O_2$ max values have been used (Costill et al, 1973; Farrell et al, 1979 and Getchell et al, 1977). If the men and women in this study are treated as a single group then the correlation between $\dot{V}O_2$ max and performance improves ($r = -0.89$); thus 79% of the variation in 5km performance in active men and women in the present study can be explained by variation in the maximal oxygen uptake.

The Oxygen Cost of Submaximal Running ($\dot{V}O_2$ submax)

During submaximal treadmill running both men and women ran at three common speeds. There was no significant difference in the oxygen cost of submaximal treadmill running between the men and women at these speeds, suggesting that there are no sex differences in the aerobic demands of submaximal treadmill running (Fig. 1). This is consistent with results reported by Daniels (1977) and Mayhew et al (1979); although Bransford and Howley (1977) found a significant difference in the oxygen cost of running between untrained males and untrained females. These latter authors also reported that trained subjects were more economical, i.e. utilised less oxygen than untrained subjects at the same running speed.

Running Economy and Performance

Differences in running economy between individuals may be related to differences in running performance (Daniels, 1974; McMiken and Daniels, 1976; Conley and Krahenbuhl, 1980) Sjödin and Schéle, 1982). Conley and Krahenbuhl (1980) showed that 65.4% of the variation in 10km performance times, in a group of athletes with similar $\dot{V}O_2$ max values, was accounted for by the variation in running economy. Sjödin and Schéle (1982) also reported a strong correlation ($r = -0.74$; $p < 0.05$) between the oxygen cost of running at 4.47 $m.s^{-1}$ and performance over 3.2km. Costill and co-workers (1979) by comparison found only a modest correlation ($r = -0.59$; $p < 0.05$) between the oxygen cost of running at 4.17 $m.s^{-1}$ and performance over 3.2km. Costill and co-workers (1973), studying a group of runners with a range of $\dot{V}O_2$ max values, also examined running economy at 4.47 $m.s^{-1}$ and commented that the oxygen consumption at that speed had "no apparent relationship to running performance". In the present study the correlations between running economy at 3.13 $m.s^{-1}$ and performance were modest $r = 0.39$ ($p < 0.01$) and $r = 0.34$ ($p < 0.05$) for the men and women respectively. Treating the men and women as a single group, the correlation between running economy and performance was $r = 0.24$ ($p < 0.05$).

Sustained high speed running demands a high rate of energy expenditure and the utilisation of a highly developed oxygen transport system (Costill et al, 1973). The performance times (Table II) for the men and women in the present study represented an average "race pace" of 4.22 and 3.41 $m.s^{-1}$ (or 6.22 and 7.43 min per mile) respectively. The men consumed oxygen at an estimated rate of 50.3 + 5.4 $ml.kg.^{-1}min^{-1}$ compared with an estimated 41.3 ± 4.5 $ml.kg.^{-1}min^{-1}$ for the women ($p < 0.01$). As may have been expected strong correlations were found between the estimated oxygen consumption at race pace (VO_2 $ml.kg.^{-1}min^{-1}$) and performance for both the male ($r = -0.86$; $p < 0.01$) and female ($r = 0.79$; $p < 0.01$) subjects. Similarly, Farrell and co-workers (1979) found a strong correlation ($r = 0.87$; $p < 0.01$) between oxygen consumption at 3.2km pace and performance. To paraphrase Farrell and co-workers (1979), 5km performance is closely related to the ability to maintain a large oxygen consumption, independent of what fraction this represents of the $\dot{V}O_2$ max.

TABLE III

Maximal oxygen uptake, running performance (min), estimated oxygen cost and estimated %$\dot{V}O_2$ max at 5km pace[a] ($m.s^{-1}$) and at 3.13 ($m.s^{-1}$) for two 'economical' and two 'uneconomical' subjects

Subject	$\dot{V}O_2$ max ($ml.kg.^{-1}min^{-1}$)	5km time (min)	Performance $\dot{V}O_2$ ($ml.kg.^{-1}min^{-1}$)	Performance %$\dot{V}O_2$ max	Running Economy $\dot{V}O_2$ ($ml.kg.^{-1}min^{-1}$)	Running Economy %$\dot{V}O_2$ max
A (Male)	59.2	18.43	49.7	84.0	34.4	58.1
B (Male)	59.3	19.63	49.9	84.2	39.9	67.3
C (Female)	47.2	22.27	40.9	86.7	34.4	72.9
D (Female)	47.6	24.60	40.5	85.1	37.8	79.4

[a] Calculated from individual regression equation

Sjödin and Schéle (1982) reported a range of 14.4 $ml.kg.^{-1}min^{-1}$ in the oxygen consumption at 4.17 $m.s^{-1}$ for a group of long-distance runners, who also demonstrated a range of $\dot{V}O_2$ max values and large variations in performance over 5km. In the present study the range of oxygen uptake at 3.13 $m.s^{-1}$ was 12 $ml.kg.^{-1}min^{-1}$ in the male subjects and 14.2 $ml.kg.^{-1}min^{-1}$ in the females.

While those men and women who recorded similar $\dot{V}O_2$ max values were able to consume similar amounts of oxygen and utilise approximately 90% $\dot{V}O_2$ max at 5km pace, differences in $\dot{V}O_2$ max did not account fully for differences in running performance (Table III). Where individuals possessed similar $\dot{V}O_2$ max values differences in running economy may have accounted for differences in performance. Partial correlational analysis (performance, $\dot{V}O_2$ max and running economy at 3.13 $m.s^{-1}$) did not reveal any strong relationship between $\dot{V}O_2$ max and running economy $r = 0.10$ (ns; men) $r = 0.45$ ($p < 0.01$; women) and $r = 0.33$ ($p < 0.01$; men and women).

Relative Exercise Intensity (%$\dot{V}O_2$ max)

When running economy is expressed as relative exercise intensity (%$\dot{V}O_2$ max), strong correlations with running performance are observed because this "value expresses both the effects of $\dot{V}O_2$ max and running economy, which may both be separately related to performance" (Sjödin and Svedenhag, 1985). Costill and co-workers (1973) found the %$\dot{V}O_2$ max at 4.47 $m.s^{-1}$ correlated highly ($r = -0.94$) with performance in a 10 mile race. A similar correlation was found by Sjödin and Schéle (1982) between %$\dot{V}O_2$ max at 4.17 $m.s^{-1}$ and performance over 5km. In the present study strong correlations were found between the %$\dot{V}O_2$ max at 3.13 $m.s^{-1}$ and performance for the men ($r = 0.85$; $p < 0.01$) and women ($r = 0.84$; $p < 0.01$) respectively. These correlations were similar to those reported for $\dot{V}O_2$ max and running performance.

The estimated relative exercise intensity during 5km performance was 87.0 ±5.8% $\dot{V}O_2$ max and 88.2 ± 5.1% $\dot{V}O_2$ max for the men and women respectively (ns). These values are lower than the 93.6 ± 3.2% $\dot{V}O_2$ max utilised over 5km by elite distance runners (Davies and Thompson, 1979) and the 92.1 ± 4.7% $\dot{V}O_2$ max utilised by young male middle-distance runners (Colquhoun, 1984). The slightly lower %$\dot{V}O_2$ max sustained by the subjects in the present study may reflect differences in both training and experience compared with the %$\dot{V}O_2$ max sustained by the elite runners. The %$\dot{V}O_2$ max values quoted above were not corrected for air resistance (Pugh, 1970). Recently Davies (1980) has estimated the extra energy cost of overcoming air resistance in outdoor track running to be 4% at middle-distance speeds.

The relationship between 5km running performance and $\dot{V}O_2$ max could be described in the form of a linear regression equation for both the men and women. Thus for the men maximal oxygen uptake, $\dot{V}O_2$ max, (y value; $ml.kg.^{-1}min^{-1}$) could be predicted from a 5km performance time (x value; min) using the equation:

$$\dot{V}O_2 \text{ max} = 104.0 - 2.32 \text{ (5km time)}$$

with an estimated standard deviation of 3.3 $ml.kg.^{-1}min^{-1}$. The corresponding equation for the women in this study was:

$$\dot{V}O_2 \text{ max} = 75.7 - 1.19 \text{ (5km time)}$$

with an estimated standard deviation of 2.9 $ml.kg^{-1}min^{-1}$. The relationship between $\dot{V}O_2$ max and 5km time shown in Fig. 2 is curvilinear over the full range of $\dot{V}O_2$ max values. If the results are redrawn as a log-log plot ($\log_e$ or $\log_{10}$) then the linear relationship between $\dot{V}O_2$ max and 5km time is described by the following equation:

$$\log_e \dot{V}O_2 \text{ max} = 6.54 - 0.844 \log_e \text{ (5km time)}$$

with an estimated standard deviation of 0.1. The correlation between $\dot{V}O_2$ max and 5km time increases from $r = -0.89$ to $r = -0.91$ using a log-log plot.

SUMMARY

The correlation between 5km running performance and $\dot{V}O_2$ max in active men and women was $r = -0.89$ ($p < 0.01$). The results of this study suggested that the relative running economy may discriminate between individuals possessing similar $\dot{V}O_2$ max values in terms of 5km performance. The linear regression equations presented for both men and women in this study may be used to give an estimate of the maximal oxygen uptake ($ml.kg.^{-1}min^{-1}$) from a 5km performance run (min). The difference between the performance times recorded by the men and women in the present study is best explained by differences in their respective $\dot{V}O_2$ max values.

References

Åstrand, P.-O. and Rodahl, L., 1977. Textbook of Work Physiology. New York: McGraw-Hill.

Bland, P. K., 1982 "The influence of training on the maximum oxygen uptake and endurance capacity of male and female subjects". M.Phil. thesis Loughborough University, Loughborough, England.

Bransford, D. R. and Howley, E. T., 1977 "Oxygen cost of running in trained and untrained men and women". Med.Sci.Sports 9 (1): 41-44.

Colquhoun, D., 1984 "Physiological responses to 5km running". M.Sc. Dissertation Loughborough University, Loughborough, England.

Conley, D. L. and Krahenbuhl, G. S., 1980 "Running economy and distance running performance of highly trained athletes". Med.Sci.Sports 12 (5): 357-360.

Costill, D. L. and Fox, E. L., 1969 "Energetics of marathon running". Med.Sci.Sports 1 (2): 81-86.

Costill, D. L., Bowers, R. and Kammer, W. F., 1970 "Skinfold estimates of body fat among marathon runners". Med.Sci.Sports 2: 93-95.
Costill, D. L., Branam, G., Eddy, D. and Sparks, K., 1971 "Determinants of Marathon Running Success". Int.Z.Angew.Physiol. 29: 249-254.
Costill, D. L., Daniels, J., Evans, W., Fink, W., Krahenbuhl, G. and Saltin, B., 1976 "Skeletal muscle enzymes and fiber composition in male and female track athletes". J.Appl.Physiol. 40 (2): 149-154.
Costill, D. L., Thomason, H. and Roberts, E., 1973 "Fractional utilization of the aerobic capacity during distance running". Med.Sci.Sports 5 (4): 248-252.
Daniels, J., 1974 "Physiological Characteristics of Champion Male Athletes". Res.Quart. 45: 342-348.
Daniels, J., Krahenbuhl, G., Foster, C., Gilbert, J. and Daniels, S., 1977 "Aerobic responses of Female Distance Runners to Submaximal and Maximal Exercise". Ann.N.Y.Acc.Sci. 301: 726-733.
Davies, C. T. M., 1980 "Effects of wind assistance and resistance on the forward motion of a runner". J.Appl.Physiol.: Resp.Env.Ex.Physiol. 48 (4): 702-709.
Davies, C. T. M. and Thompson, M. W., 1979 "Aerobic Performance of Female Marathon and Male Ultramarathon Athletes". Eur.J.Appl.Physiol. 41: 233-245.
Drinkwater, B. L., 1973 "Physiological responses of women to exercise". In: Exercise and sport sciences reviews, Wilmore, J. H. (Ed.). New York: Academic Press Inc.
Durnin, J. V. G. A. and Rahaman, M. M., 1967 "The assessment of the amount of fat in the human body from measurements of skinfold thickness". Br.J.Nutr. 21: 681-689.
Farrell, P. A., Wilmore, J. H., Coyle, E. F., Billing, J. E. and Costill, D. L., 1979 "Plasma lactate accumulation and distance running performance". Med.Sci.Sports 11 (4): 338-344.
Getchell, L. H., Kirkendall, D. and Robbins, G., 1977"Prediction of Maximal Oxygen Uptake in Young Adult Women Joggers". Res.Quart. 48: 61-67.
Hagan, R. D., Strathman, T., Strathman, L. and Gettman, L. R., 1980 "Oxygen uptake and energy expenditure during horizontal treadmill running". J.Appl.Physiol.: Resp.Env.Ex.Physiol. 49 (4): 571-575.
Mayhew, J. L., Piper, F. C. and Etheridge, G. L., 1979 "Oxygen cost and energy requirement of running in trained and untrained males and females". J.Sports Med. 19: 39-44.
McMiken, D. F. and Daniels, J. T., 1976 "Aerobic requirements and maximum aerobic power in treadmill and track running". Med.Sci.Sports 8 (1): 14-17.
Pollock, M. L., 1977 "Submaximal and Maximal Working Capacity of Elite Distance Runners". Part 1. Cardiorespiratory Aspects. Ann.N.Y.Acc.Sci. 301: 310-322.
Pugh, L. G. C. E., 1970 "Oxygen intake in track and treadmill running with observations on the effects of air resistance". J.Physiol. 207: 823-835.
Saltin, B. and Åstrand, P. O., 1967 "Maximal Oxygen Uptake in Athletes". J.Appl.Physiol. 23: 353-358.
Sjödin, B. and Jacobs, I., 1981 "Onset of Blood Lactate Accumulation and Marathon Running Performance". Int.J.Sports Med. 2: 23-26.
Sjödin, B. and Schéle, R., 1982 "Oxygen Cost of Treadmill Running in Long Distance Runners". In: Exercise and Sport Biology, Ed. Komi, P. V. 61-67, Human Kinetics, Illinois.
Sjodin, B. and Svedenhag, J., 1985 "Applied Physiology of Marathon Running". Sports Med. 2: 83-99.
Taylor, H. L., Buskirk, E. and Henschel, A., 1955 "Maximal Oxygen Intake as an Objective Measure of Cardiorespiratory Performance". J.Appl.Physiol. 8: 73-80.
Wells, C. L., 1985. Women, sport and performance. Champaign, Illinois: Human Kinetics.
Wells, C. L., Hecht, L. H. and Krahenbuhl, G. S., 1981 "Physical Characteristics and Oxygen Utilization of Male and Female Marathon Runners". Res. Quart. for Ex. and Sport 52 (2): 281-285.
Williams, C., 1981 "The Biological Basis of Aptitude: The Endurance Runner". J.biosoc.Sci. Suppl. 7: 103-112.
Williams, C. and Nute, M. L. G., 1983 "Some Physiological Demands of a Half-Marathon Race on Recreational Runners". Br.J.Sports Medicine 17: 152-161.
Wilmore, J. H. and Harmon Brown, C., 1974 "Physiological Profiles of Women Distance Runners". Med.Sci.Sports 6 (3): 178-181.

BOOK REVIEW

Title: **COMMON SPORTS INJURIES IN YOUNGSTERS**
Authors: R. B. Birrer and D. B. Brecher
Publishers: Medical Economic Books, New Jersey
Price £24.20 + £1.50 p & p 144 pages incl. Index Figs. and Tables ISBN 0-87489-420-4

This paperback is written by Americans for Americans and as such appears comprehensive and useful for the intended readership.

It is a difficult book for a British reviewer to assess and its general application to those concerned with sports medicine in schoolchildren in this country seems limited. The text is liberally sprinkled with eponyms. A sentence on page 66 intrigued me:– "These include the drop-arm, apprehension, Yergason, Gilchrest, Ludington, Lippman, Booth and Marval tests". In over 34 years of close involvement with sports injuries to the adolescent I never heard of, let alone performed, any of these tests and I feel no guilt. My mind boggled over the precise meaning of "A poorly executed crossover step while cutting can sprain the lateral ligament of the planted leg" (page 112).

I recommend this book to North American readers mainly.

John Sparks